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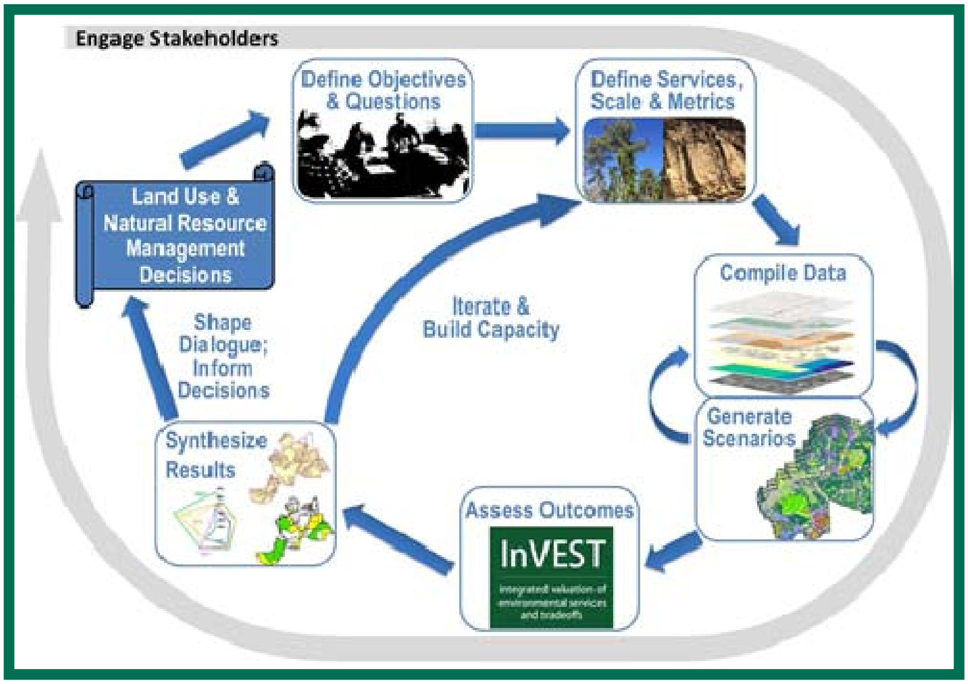

Enlisting Ecosystem Services: Quantification and Valuation of Ecosystem Services to Inform Base Management

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14. ABSTRACT

An integrated understanding of the natural and social implications of land-use decisions can lead to more effective land management in the DoD using an ecosystem service approach developed by the Natural Capital Project. The approach provides estimates of the values of natural capital through iterative stakeholder engagement, scenario planning, biophysical and economic/social modeling with free, open-source InVEST (Integrated Valuation of Environmental Services and Tradeoffs) software, and synthesis of multi-service outputs. In coordination with installation personnel, we applied our approach to multiple-use landscape management at three DoD installations by evaluating ecosystem services under future scenarios that reflect alternative military missions and natural resource management strategies. The tested approach and tools are especially helpful in 1) offering a mechanism for incorporating ecosystem services into the existing ecosystem-based management framework employed by the DoD for spatial planning and resource management, 2) providing spatially explicit, quantitative estimates of current and future ecosystem services to complement field observations and qualitative measures common in current environmental impact assessments, and 3) demonstrating a flexible, modular structure to aggregate various types of information (e.g.,training activities, cultural resources) and tools (e.g., SWAT, HexSim)to support a more comprehensive assessment of changes in

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ACRONYMS AND ABBREVIATIONS

ac	acre
ACUB	Army Compatible Use Buffer
ARIES	ARtificial Intelligence for Ecosystem Services
BAU	business-as-usual
BMP	Best Management Practice
BRAC	Base Realignment and Closure
CWASSC	Clean Water Act Services Steering Committee
DISP	Defense Installation Strategic Plan
DoD	U.S. Department of Defense
DoDI	Department of Defense Instruction
EPA	Environmental Protection Agency
ESA	Endangered Species Act
ESTCP	Environmental Security Technology Certification Program
GHMTA	Good Hope Maneuver Training Area
GIS	Geographic Information System
ha	hectare
HBDT	High Budget-Decreased Training
HBIT	High Budget-Increased Training
HRA	Habitat Risk Assessment
INRMP	Integrated Natural Resource Management Plan
InVEST	Integrated Valuation of Environmental Services and Tradeoffs
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
JBLM	Joint Base Lewis-McChord
LBDT	Low Budget-Decreased Training
LBIT	Low Budget-Increased Training
LEF	long-term ecological forestry
LULC	land use/land cover
MCoE	Maneuver Center of Excellence
MIMES	Multiscale Integrated Model of Ecosystem Services
mm	millimeter
MSA	mean species abundance
NatCap	Natural Capital Project

ACRONYMS AND ABBREVIATIONS (continued)

NBCD	National Biomass and Carbon Dataset
NEPA	National Environmental Policy Act
NGO	non-governmental organization
NPDES	National Pollutant Discharge Elimination System
PES	Payment for Ecosystem Services
PO	performance objective
RCW	red-cockaded woodpecker
REPI	Readiness and Environmental Protection Initiative
RUSLE	Revised Universal Soil Loss Equation
SCT	short-term concentrated training
SDT	short-term diffuse training
SERDP	Strategic Environmental Research and Development Program
SSC	suspended sediment concentration
SWAT	Soil and Water Assessment Tool
TA	training area
T&E	threatened and endangered
TMDL	Total Maximum Daily Load
UK	United Kingdom
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

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EXECUTIVE SUMMARY

OBJECTIVES OF THE DEMONSTRATION

The full suite of environmental benefits accruing to or affected by federal land management activities typically is not accounted for in decision-making processes, leading to uncertainty in planning and unnecessary costs to the agencies and society at large. Federal agencies are increasingly interested in adopting an ecosystem service approach to address some of their unique resource management challenges. A clear understanding of ecosystem service values and their interconnections would help them balance mandated mission activities with environmental stewardship requirements, sustain multiple uses of lands, evaluate environmental impacts for proposed actions or policies in compliance with the National Environmental Policy Act, resolve land use conflicts within and among agencies, and communicate management objectives with Congress and the public. However, evaluating ecosystem services at scales and in currencies that are relevant to everyday decision-making processes is an important gap in natural resource management, and few tools exist that can be applied in a systematic, consistent manner across sites at the spatial scales and time frames relevant to major decisions.

This project aims to demonstrate an integrated ecosystem service methodology for incorporating the provision and value of ecosystem services and biodiversity into management decisions of U.S. Department of Defense (DoD) installations. The approach uses a novel, open-source software package to estimate the relative benefits of alternative land uses, military activities, and protection or restoration of habitats for species at risk on installations. Additionally, this project provides the DoD with support to enable technology integration into overall installation management.

TECHNOLOGY DESCRIPTION

The ecosystem services approach developed by The Natural Capital Project (NatCap) provides estimates of the values of natural capital in clear, credible, and practical ways through iterative stakeholder engagement, scenario planning, biophysical and economic/social modeling with Integrated Valuation of Environmental Services and Tradeoffs (InVEST), and multi-service synthesis of outputs. InVEST is a free and open-source software tool that can be used with a number of Geographic Information System (GIS) software packages to integrate ecosystem service values into decision-making. InVEST is best used as part of a decision process, and entails linking credible models based on ecological production functions and diverse valuation methods. InVEST has been developed since 2006 by NatCap (naturalcapitalproject.org). This tool has been applied and tested in over 20 demonstrations around the world with a rapidly growing user base.

DEMONSTRATION RESULTS

The project team demonstrated the ecosystem services approach and InVEST tools at three DoD installations: Joint Base Lewis-McChord (JBLM), Washington; Fort Pickett, Virginia; and Fort Benning, Georgia. A majority of the quantitative and qualitative performance objectives were successfully attained across the three sites. The objectives include developing management scenarios jointly with installation personnel; applying InVEST and ancillary models to quantify, value, and map ecosystem services; examining the tradeoffs and synergies among multiple services based on absolute and relative estimates; conducting uncertainty analysis and model validation;

identifying decision-informing opportunities; and evaluating ease of use and user acceptance of results.

For the JBLM case, tradeoffs and synergies were examined among five ecosystem services (prairie habitat provision, infantry and vehicle training capacities, timber production, and carbon sequestration) under a business-as-usual scenario and four alternative scenarios of varied training intensities and budgets for resource management. For the Fort Pickett case, the ecological suitability of alternative siting choices was evaluated for a hypothetical training range as an abbreviated demonstration of the ecosystem service approach. Nine reasonable siting locations were identified and the ecosystem impacts of creating a new firing range at each location were assessed—quantifying effects on carbon storage, biodiversity, and sediment export. Recommendations of suitable siting choices were provided based on the aggregated ecosystem impacts. For the Fort Benning case, the ecosystem services approach was applied to the installation and adjacent lands purchased, or soon to be acquired, as part of the Army Compatible Use Buffer program (ACUB). The tradeoffs and synergies were examined among three ecosystem services, i.e., provision of low-risk habitat for federally endangered red-cockaded woodpecker (RCW), sediment retention, and carbon sequestration, under two 20-year scenarios that differ in the spatial distribution of mechanized training activities, and a 100-year ecological forestry scenario featuring adaptive longleaf pine restoration.

Six performance objectives were evaluated for the approach with a post-demonstration survey of installation personnel. The response scores ranged from 3.9 to 4.6 on a 5-point Likert scale, indicating general acceptance of the ecosystem service approach and assessment results. The qualitative analysis suggests the tested approach and tools are especially helpful in: 1) offering a mechanism for incorporating ecosystem services into existing spatial planning and resource management processes; 2) providing spatially explicit, quantitative estimates to inform environmental impact assessments; and 3) demonstrating a flexible, modular structure to aggregate various types of information (e.g., training activities, cultural resources) and tools to support a more comprehensive assessment of changes in biodiversity and multiple ecosystem services. Due to lack of technical capacity and additional software certification requirements, installation staff at the three demonstration sites were unable to use InVEST independently, but they provided positive feedback on the value of the analytical approach and the scenario generation process.

IMPLEMENTATION ISSUES

Five key lessons were learned throughout the demonstration: 1) an iterative and interactive approach is needed to define when and what kind of ecosystem service information is critical to create useful, credible science and change in a decision process and outcomes; 2) as for any modeling tool, it is important to understand appropriate uses of InVEST results; 3) value of ecosystems should be conveyed in metrics related to the organization's decision context; 4) successful adaptation of InVEST requires technical capacity; and 5) policy incentives and centralized data support may facilitate adoption of InVEST and the ecosystem service approach.

Pre- and post-processing capabilities and an online training curriculum were also developed to further facilitate adoption of the ecosystem service approach and InVEST tools.

1.0 INTRODUCTION

Land management decisions can have significant societal impacts that are presently difficult to include in assessment approaches. It is challenging to forecast the impacts of land management and land use change in a systematic way because the provision of such ecosystem benefits as flood control, water quality, climate stability, and wildlife habitat depends on the cumulative effects of biophysical processes occurring at different scales. The U.S. Department of Defense (DoD), as a manager of expansive tracts of land and waters, both depends upon and impacts these ecosystem services. Typically, the full suite of environmental benefits enjoyed or impacted by the DoD is not accounted for in decision-making practices, leading to uncertainty in planning and unnecessary costs to the DoD and society at large. The goal of demonstrating an integrated ecosystem services approach using the software, Integrated Valuation of Environmental Services and Tradeoffs (InVEST), at three DoD installations is to identify the benefits of making resource- and land-use decisions with spatially explicit information about the tradeoffs and synergies between intensive land uses and ecosystem service provision.

1.1 BACKGROUND

After decades spent struggling to fence nature off from people, natural resource managers and developers are moving toward a middle ground where conservation and development goals are integrated (Ninan, 2009). This shift is evidenced by novel policy mechanisms introduced around the world in the last decade, including the establishment of water funds and other Payment for Ecosystem Services (PES) programs, market-based land-use regulation such as conservation and wetland mitigation banking, and international carbon markets (Daily et al., 2000; Ecosystem Marketplace, 2013). Federal agencies are increasingly interested in integrated approaches to address some of their unique resource management challenges: balancing mandated mission activities with environmental stewardship, sustaining multiple uses of lands (e.g., resource conservation, wildlife protection, recreation, and energy development), evaluating environmental impacts for proposed actions or policies in compliance with the National Environmental Policy Act (NEPA), resolving land use conflicts within and among agencies, and communicating management objectives with Congress and the public. Aligned with many other federal agencies, the DoD has started exploring ways to better assess and communicate the value of the environmental services provided by the natural assets upon which their enterprises depend.

In spite of growing interest in evaluating ecosystem services, doing so at scales and in currencies that are relevant to everyday decision-making processes is still an important gap in natural resource management. Although a number of ecosystem service assessments have been conducted (Imperial, 1999; United Kingdom (UK) NEA, 2001; Millennium Ecosystem Assessment, 2005; CONABIO, 2006; Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) Catalogue of Assessments for sub-global assessments; Daily et al., 2013) and a wide variety of ecosystem services analytical tools are being developed (Waage and Kester, 2013), few tools can be applied in a systematic, consistent manner across sites at the spatial scales and time frames relevant to major decisions. A major challenge in creating such tools is sufficient information to develop simple ecological production functions that define how changes in the structure and function of ecosystems impact the delivery of ecosystem services. InVEST is designed to address these issues and to improve land- and water-use decisions by quantifying and mapping changes to a suite of ecosystem services and their values across multiple scales (Kareiva et al., 2011).

Installation managers at the DoD are keenly aware that maintaining the environmental resources on each installation can help the DoD successfully meet its mission. One challenge for installations is to meet regulatory requirements related to such attributes as allowable sediment concentrations in water bodies, and habitat conservation for federally listed species and wetland areas. In addition, active management of greenhouse gas emissions may be necessary when land management practices result in an installation being either a source or a sink. At the same time, carrying out DoD's military mission requires that testing and training opportunities are not significantly diminished due to existing or potential future regulations, or encroachment from expanding civilian population centers. Quantitative assessments of how management activities affect different ecosystem services, in addition to habitat for listed species, would help the DoD manage these multiple objectives by identifying methods to minimize costs of regulatory compliance and maximize social benefits from management investments.

The DoD also makes decisions about the types of testing and training activities that are allowed (or prohibited) in different regions of its lands. InVEST models are spatially explicit and enable examination of the consequences of different zoning rules for testing and training and the siting of associated infrastructure. Using ecosystem service assessments, the DoD can manage its landscapes to balance necessary testing and training exercises with natural resource stewardship, thereby minimizing impacts that result in costly treatment, regulatory burden, or strained relations with the public. Moreover, those mission activities that are themselves dependent on continued provisioning of particular ecosystem services are likely more sustainable.

The Defense Installation Strategic Plan (DISP) aims to ensure that installations have the necessary assets and services to support military forces in a cost-effective, safe, sustainable, and environmentally sound manner. Programs such as the Readiness and Environmental Protection Initiative (REPI) are designed to aid in off-installation conservation to provide relief for mission activities on installations. InVEST could be an effective complement to these existing efforts by broadening the costs and benefits considered by installation managers when they scope management improvements and alternatives.

1.2 OBJECTIVE OF THE DEMONSTRATION

This project demonstrated an integrated ecosystem service methodology for incorporating the provision and value of ecosystem services and biodiversity into management decisions of DoD installations using a novel, open-source software package to estimate the relative benefits of alternative land uses, military activities, and protection or restoration of habitats for species at risk on installations. Additionally, the project team provided DoD with support to enable technology integration into overall installation management.

Specific quantitative objectives achieved through the demonstration include:

- Quantify provision of ecosystem services using existing Geographic Information System (GIS) data;
- Quantify value of ecosystem services using existing GIS data for at least two key ecosystem services;
- Provide spatially-explicit rendering of service provision;

- Provide spatially-explicit rendering of the social value of at least two key services;
- Assess degree to which model results depict reality, and compare Tier 1 versus Tier 2 performances against observations;
- Incorporate uncertainty into service-provision estimates for at least two key services;
- Convert alternative management scenarios into realistic alternative land use/land cover (LULC) maps;
- Estimate absolute and relative changes in each ecosystem service that will result from alternative management options; and
- Use service maps to evaluate multiservice impact of alternative management options for at least two services.

Specific qualitative objectives achieved through the demonstration include:

- Identify opportunities for InVEST to inform decision-making process;
- Identify priority DoD management themes and ecosystem services to be used in modeling scenarios;
- Document whether information on ecosystem services is incorporated into decision-making process;
- Report ease of use of InVEST as compared with more complex models; and
- Assess user acceptance of project outcomes.

1.3 REGULATORY DRIVERS

Pursuant to a 1997 amendment to the Sikes Act, DoD installations must regularly prepare Integrated Natural Resource Management Plans (INRMP) to ensure the integrity of natural resources in a way that both sustains military operations and is consistent with federal and state stewardship and legal requirements (DoD, 2012). Under the Federal Endangered Species Act (ESA), DoD installation managers are required to ensure their actions do not adversely impact or modify critical habitat of threatened and endangered (T&E) species. The Clean Water Act is the primary regulation that directs the restoration and protection of water resources on DoD Installations through requirements on National Pollutant Discharge Elimination System (NPDES) for permitting discharges, Total Maximum Daily Loads (TMDL), non-point source runoff, and natural resource protection, etc. (Clean Water Act Services Steering Committee [CWASSC], 2004). Additionally, watershed management on installations is also encouraged by a Unified Federal Policy that was adopted by the DoD in 2000 (Federal Register, 2000). The DoD has long pursued an integrated, ecosystem-based approach to management, and has recently incorporated ecosystem services in agency-wide policy. Department of Defense Instruction (DoDI) 4715.3 of 1996 first called for the integrated management of natural and cultural resources on DoD lands (DoD, 1996). In 2011, an update to this instruction, DoDI 4715.03, explicitly states it is DoD policy to “sustain the long-term ecological integrity of the resource base and the ecosystem services they provide” (DoD, 2011). The DoD-wide commitment to ecological forestry management is demonstrative of this multi-service, ecosystem-based approach, which emphasizes the maintenance of multiple ecosystem services in forests, such as habitat for realistic training settings, carbon sequestration, and native biological diversity (DoD, 2011; SERDP, 2011). Prospects of regulation for greenhouse gas on public lands emissions, as exemplified by Executive Order 13514 (Executive Order 13514, 2009), also drive DoD installations to consider sustainable land management that maintains installation lands and coastal environments as carbon sinks.

2.0 TECHNOLOGY/METHODOLOGY DESCRIPTION

This section presents the ecosystem services approach developed by the Natural Capital Project (NatCap) and the InVEST tool for quantifying, mapping, and valuing ecosystem services. It also provides a brief comparison between InVEST and other tools that evaluate ecosystem services.

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

The ecosystem services approach developed by NatCap provides estimates of the values of natural capital in clear, credible, and practical ways through iterative stakeholder engagement, scenario planning, biophysical and economic/social modeling with InVEST, and multi-service synthesis. InVEST is a free and open-source software tool that can be used with a number of GIS software packages to integrate ecosystem service values into decision-making (Sharp et al., 2014). InVEST is designed to integrate ecosystem service values into decision-making by, linking credible scientific models based on ecological production functions and various valuation methods. It enables decision-makers to assess the tradeoffs associated with alternative policy options, and to identify areas where investment in ecosystem services can enhance human development and conservation of terrestrial, freshwater, and marine ecosystems. The InVEST toolset currently includes 17 distinct InVEST models suited to terrestrial, freshwater, and marine ecosystems, and additional supporting tools for scenario development and post-processing of results. InVEST has been developed since 2006 by NatCap, a partnership among Stanford University, The Nature Conservancy, World Wildlife Fund, and the University of Minnesota. This tool has been applied and tested in over 20 demonstrations around the world (Ruckelshaus et al., 2013) with a rapidly growing user base.

InVEST is most effectively used within a decision-making process that starts with stakeholder consultations. InVEST users can identify questions of interest, management choices, and/or policy options through discussion with stakeholders. Spatial scenarios can then be jointly developed to show, for example, several alternative locations where a new training facility might be built, where forest might be converted to open area for vehicle maneuver, or where best management practices (BMP) (e.g., riparian buffer, longleaf pine restoration, prescribed fire) are expected to affect soil erosion or habitat for species at risk. Scenarios typically include maps of potential future LULC, which are critical inputs in all InVEST models. Following stakeholder consultations and scenario development, InVEST can estimate how the current location, amount, delivery, and value of relevant services are likely to change in the future. InVEST models are spatially-explicit, using maps as information sources and producing maps as outputs. InVEST returns results in either biophysical terms (e.g., tons of carbon sequestered) or economic terms (e.g., net present value of that sequestered carbon). InVEST results can be synthesized across multiple ecosystem services, which are interconnected through their dependence on LULC, to reveal the impacts of management choices or policy options represented and to inform decisions for stakeholders. The spatial resolution of analyses is also flexible, allowing users to address questions at the local, regional, or global scales.

InVEST hydrological models have been tested and validated in a number of watersheds and have shown consistent agreement with observed data or with the popular data-intensive Soil and Water Assessment Tool (SWAT) (Conte et al., 2011; Mendoza et al., 2011). The Habitat Risk Assessment

(HRA) model has been tested in Belize for coral reef, seagrass, and mangrove habitats (Arkema et al., 2014) and the predicted risk estimates strongly correlate with the observed habitat quality.

InVEST currently contains both standalone tools in the Microsoft Windows operating system and ArcGIS-dependent script tools. Most models have full functionality as standalone tools for higher stability and efficiency in performance. GIS software (e.g., open source QGIS or ArcGIS) is required to compile data and visualize results for standalone tools. NatCap provides continued development and improvement of InVEST with user support and trainings.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY/METHODOLOGY

There are multiple efforts currently aimed at the development of software packages to facilitate increased understanding of the suite of impacts associated with land-use decisions. Notable alternatives to InVEST that focus on evaluating multiple services under different management scenarios and spatial scales include ARtificial Intelligence for Ecosystem Services (ARIES) and Multiscale Integrated Model of Ecosystem Services (MIMES).

Although InVEST and its two alternatives are all free and open-source tools, InVEST features four advantages. First, InVEST models utilize peer-reviewed, transparent ecological production functions and location-specific data in order to avoid potential pitfalls associated with benefits-transfer approaches, as encountered using ARIES. Second, current InVEST models can be specified at different levels of sophistication according to data availability and risk tolerance of decision-makers. Third, InVEST is available for independent application anywhere in the world; users specify the areas and ecosystem services of interest. ARIES online data were primarily compiled for a few case studies, and MIMES models were designed for particular applications. Thus, users of either ARIES or MIMES tools would likely need to work with model developers for applications beyond their existing examples. Fourth, InVEST can be applied for a larger number of ecosystem services in terrestrial, freshwater, and marine ecosystems compared to its alternatives, with more models in development. InVEST also provides more comprehensive documentation, including peer-reviewed approaches, user support, and training materials for individual models compared to ARIES and MIMES.

However, InVEST has a few limitations about which users should be aware. As models are designed to require relatively few data to broaden the range of applicable locations and decision contexts, some simplifying assumptions are made in individual models. With sufficient local data and knowledge, models can be refined to some extent on a case-to-case basis. The majority of InVEST Tier 1 models are designed on an annual time step, which is reasonable for services such as carbon sequestration, but may be less relevant for analyzing water-related services in locations with heterogeneity in seasonal rainfall patterns or water use. In addition, previous demonstration experience suggests that creating relevant and realistic scenarios for InVEST can be time-intensive—as is the case for all ecosystem service models—and successful independent model runs would require some site-specific data and GIS expertise at the partner sites.

3.0 PERFORMANCE OBJECTIVES

This section summarizes all performance objectives (PO) and their assessment results for the demonstrations at Joint-Base Lewis McChord (JBLM), Fort Pickett, and Fort Benning.

Table 1. Performance objectives.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
1. Quantify provision of ecosystem services using existing GIS data (carbon sequestration, habitat provision, sediment retention, timber production)	Service provision estimate in relevant biophysical units	LULC map, carbon pools, threat sources, harvest cycle, soil depth, precipitation, root depth, crop coefficient, etc.	Convert GIS inputs into service-specific provision outputs using ecological production functions that are documented in the peer-reviewed literature.	Criterion met for JBLM, Fort Pickett, and Fort Benning.
2. Quantify value of ecosystem services using existing GIS data for at least two key ecosystem services	Estimate of social value or market value of ecosystem service relevant to DoD	Social cost of carbon, market prices and costs of production. Local dredging costs; sedimentation load thresholds.	Convert GIS inputs into ecosystem services (above) and service-specific valuation outputs using economic valuation techniques that are documented in the peer-reviewed literature.	• JBLM: Criterion met • Fort Pickett: Criterion not met because of simplified application. • Fort Benning: Criterion met for carbon, not for sediment because of lack of threshold information.
3. Provide spatially-explicit rendering of service provision	Service-provision estimate in relevant biophysical units; maps of key ecosystem services by LULC categories that are relevant for decision-makers	As above under objective 1	Creation of one map for each focal ecosystem service that will illustrate how provision varies as a function of LULC category and location on the landscape.	Criterion met for JBLM, Fort Pickett, and Fort Benning.
4. Provide spatially-explicit rendering of the social value of at least two key ecosystem services	Estimates of ecosystem-service values to society	As above under Objective 2	Creation of maps and tables that quantify spatially explicit economic/social value for at least two key ecosystem services in dollar terms.	• JBLM: Criterion met • Fort Pickett: Criterion not met because of simplified application. • Fort Benning: Criterion met for carbon, not for sediment due to lack of threshold information.

Table 1. Performance objectives (continued).

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Qualitative Performance Objectives				
10. Identify opportunities for InVEST to inform decision-making process	Utility of scenario-based, spatially explicit ecosystem services mapping approach to decision making on base	Organization charts and chain-of-command information, steps in decision-making process	Identification of one or more decisions or steps within the natural-resource management process for integration of information from InVEST. Fort Benning personnel acceptance scores at least 4.0 in a 5-point Likert survey.	Criterion met for JBLM, Fort Pickett, and Fort Benning. (Likert score = 4.13)
11a. Document whether information on ecosystem services is incorporated into decision-making process (for JBLM and Fort Pickett)	Inclusion of ecosystem-services language in decision-making process (e.g., INRMP)	Documentation of base decision-making process pre and post-project	Documented consideration of ecosystem service information in at least one step of one base decision-making process	Criterion met for JBLM and Fort Pickett.
11b. Identify priority DoD management themes and ecosystem services to be used in modeling scenarios (for Fort Benning)	Flow diagram connecting management themes and other drivers of interest to ecosystem services	Installation INRMP, discussion with installation staff and in ESTCP	Identification of two or more management themes (e.g., ecological forestry management, water management, etc.) and associated ecosystem services of importance specifically to DoD.	Criterion met for Fort Benning.
12a. Ease of Use (for JBLM and Fort Pickett)	Personnel opinion on ease of applying InVEST	Discussion with relevant personnel about experience/ opinion with InVEST	Positive comments about ability of independent InVEST application (e.g., amassing data, establishing scenarios, running InVEST, and reporting results)	Criterion not fully met for JBLM and Fort Pickett because installations are not currently able to use InVEST.
12b. Ease of use of InVEST as compared with more complex models (SWAT and RCW models) (for Fort Benning)	Model inputs availability, processing time, skill and knowledge requirement, relevance of outputs to decisions	Model running process from Objective 5, feedback of staff who have experience with InVEST, SWAT or RCW models	Creation of tables or charts comparing ease and relevance of using InVEST models versus other models for analyzing the same ecosystem service. Fort Benning personnel acceptance scores at least 4.0 in a 5-point Likert survey.	Criterion met for Fort Benning. (Likert score = 3.9)
13. Assess user acceptance of project outcomes (Fort Benning only)	Five-point Likert scale measuring user satisfaction of Objectives 3, 5, 6, 7, 10, and 12b.	Feedback from relevant Fort Benning staff in a post-demonstration survey	Clear information on acceptance of project outcomes as indicated in the installation personnel survey. Average acceptance score should be at least 4.0 for each question and across all questions.	Criterion met for Fort Benning. (Likert score = 4.13)

red-cockaded woodpecker = RCW

4.0 SITE DESCRIPTION

This section presents concise summaries of the demonstration sites' location, physical and environmental characteristics, and brief overview of management operations.

4.1 SITE LOCATION AND HISTORY

The three installation sites are located in different parts of the U.S. and are characterized by distinct environmental conditions and natural-resource management issues. The project team demonstrated the flexibility of InVEST models and their relevance to decision-makers facing a range of decisions related to natural resources and environmental outcomes.

Figure 1. Map of installation locations in U.S.

4.1.1 Joint Base Lewis-McChord

JBLM is an approximately 35,000-hectare military reservation located in western Washington, roughly 60 kilometers south of Seattle and 11 kilometers northeast of Olympia. JBLM is a major facility for weapons qualification and field training. Training activities that characterize land use at JBLM include on/off-road vehicle movement, placement of temporary targets, gunnery practice, digging activities (vehicle positions, tactical operation centers, and foxholes), unit assembly, and unit deployment exercises.

4.1.2 Fort Pickett

Fort Pickett is located in the Piedmont physiographic province of southeastern Virginia, approximately 100 kilometers southwest of Richmond and 5 kilometers east of the town of Blackstone. Fort Pickett's primary objective is to support the training of active, reserve, and National Guard combat; combat support; and combat services support units in successful techniques of organization, deployment, and combat operations under as wide a variety of conditions as possible. These requirements make the proactive management of natural resources necessary in order to fulfill the military mission of Fort Pickett.

4.1.3 Fort Benning

Fort Benning is located in the lower Piedmont Region of central Georgia and Alabama, approximately 13 kilometers south of Columbus, GA. The installation occupies about 74,000 hectares of land; approximately 93% lies in Georgia and 7% in Alabama divided by the Chattahoochee River (Fort Benning, 2001; Sharif and Balbach, 2008). Fort Benning has transformed into the U.S. Army Maneuver Center of Excellence (MCoE), hosting a number of tenant units, including the U.S. Army Armor School and U.S. Army Infantry School. Land disturbances due to the implementation of Base Realignment and Closure (BRAC) and transformation initiatives over the last few years are estimated to affect over 19,000 acres throughout the entire installation (Fort Benning, 2001).

4.2 SITE CHARACTERISTICS

4.2.1 Joint Base Lewis-McChord

JBLM has a Mediterranean Oceanic climate with dry, warm summers and mild, wet winters. The area receives approximately 990 millimeters (mm) of rain and 203 mm of snow per year and temperature typically varies from 1°C to 25°C. Forests are the largest ecosystem type on JBLM, covering approximately 60% of the installation (21,286 hectare [ha]). Over 18,615 ha of these forests are dominated by Douglas-fir (*Pseudotsuga menziesii*), the most common tree species on JBLM. Forests are managed for realistic training and testing environment support, wildlife habitat, and timber production. Approximately 5,666 ha on JBLM (16%) are covered by either prairie or grasslands ecosystems. Prairies are managed to provide suitable open conditions for training, to maintain native populations and functions, and to control invasive species.

4.2.2 Fort Pickett

Fort Pickett is generally composed of low, gently rolling terrain with level uplands and intermittent stream drainages. Approximately 90% of Fort Pickett is in the Nottoway River drainage basin, which consists of six small tributaries that flow into the Nottoway River. Whereas the northern training area of the installation is considered a level upland, the southern training area is characterized by steeper slopes and ravines. Fort Pickett is located on the boundary between the Piedmont and the Coastal Plain soil divisions. The most common soil types are loams and sandy loams. Most of the upland soils found on Fort Pickett are not frequently flooded, have a slow to moderate infiltration rate, and are non-hydric.

4.2.3 Fort Benning

Fort Benning's climate is characterized by long hot summers and mild winters. Fort Benning is located along the Fall Line of two physiographic provinces, the Piedmont Plateau to the north and the Coastal Plain to the south, which represent distinct features of topography, geology and soils, and vegetation communities. Fort Benning is moderately sloped between 3% to 5%. Several streams originate from the dissected Fall Line flow through installation lands, supporting unique communities of aquatic flora and fauna (Fort Benning, 2006). The rolling uplands are underlain with sandy to sandy clay loams, which allows storm water to easily dislodge and transport sand grains and erode surface soils (Sharif and Balbach, 2008). Fort Benning is heavily forested with pine, mixed pine and hardwoods, and deciduous forests. Much of the mature pine woodlands, especially those dominated by longleaf pine (*Pinus palustris*), support RCW (*Picoides borealis*), a federally endangered species.

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5.0 TEST DESIGN

The goal of the demonstration is to illustrate the utility of InVEST as a decision-support tool for evaluating the impacts of alternative management options on ecosystem-service provision and value. To successfully demonstrate the usefulness of InVEST, it is important to situate the biophysical and economic analysis with InVEST into the broader ecosystem service approach that also encompasses iterative stakeholder engagement, scenario development, and synthesis of results relevant to decision making.

5.1 CONCEPTUAL TEST DESIGN

NatCap's ecosystem services approach and the InVEST tool have been designed to provide policy-relevant information to interested parties (government agencies, non-governmental organizations, and private organizations) in the hope of achieving more efficient resource-use outcomes. Specifically, the tool is devised to compare the impacts of different management scenarios on a suite of ecosystem services so that policy makers can choose the management option that meets their objectives. As highlighted in Figure 2, the analytical approach included a number of key steps that improve the likelihood of a successful application:

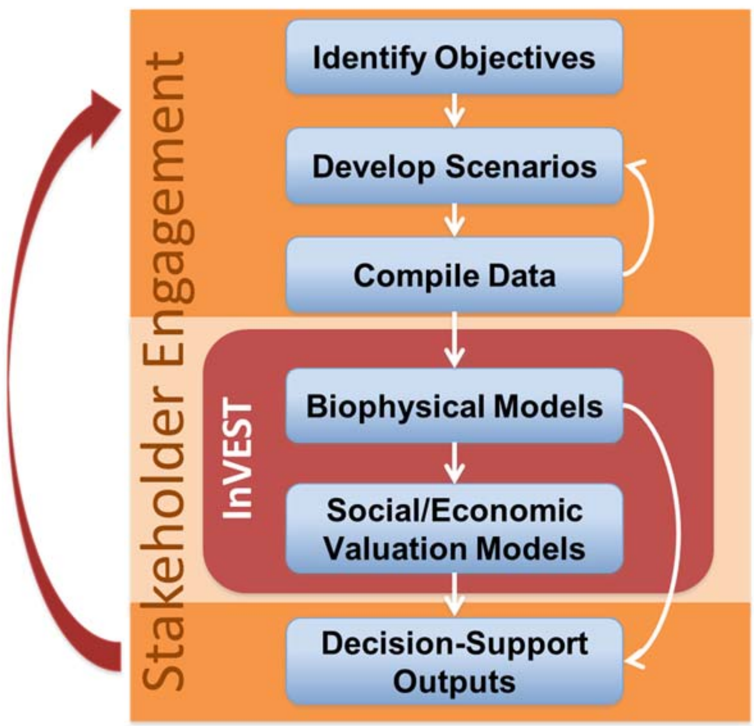

Figure 2. Conceptual design of demonstration steps and opportunities for evaluation.

- Identify Objectives with Installation Personnel

  To target ecosystem service analysis to each installation's specific decision context and environmental conditions, the project team developed a clear understanding of major environmental problems, management practices, regulatory drivers, and focal ecosystem services through interactive discussions with installation personnel, then identified key objectives to guide the application of InVEST.

- Develop Scenarios

  To represent possible future management plans, the project team worked with installation personnel to create qualitative descriptions for the potential outcomes of different future management options, then specified quantitative representations of the narratives. The potential management plans were depicted spatially on LULC maps that served as inputs to InVEST models.

- Compile Data

  Collected data from installation personnel and other relevant public agencies were used to support scenario development and ecosystem service modeling with InVEST.

- Analyze Biophysical Supply and Economic Value with InVEST Models

  The project team applied the InVEST models for relevant ecosystem services to estimate the impacts of alternative management scenarios on service provision and value. The observed data were used to calibrate the biophysical models and validate model outputs. Uncertainty in model inputs was incorporated by bounding model outputs and highlighting locations with consistently ranked service provision and value across the range of input combinations. The ecosystem service evaluated the implication of management alternatives by identifying differences in service provisions and value across the LULC types and management units associated with alternative scenarios.

- Synthesize Decision-Support Outputs

  The InVEST outputs were presented in a manner that was most useful to the decision-making context. In particular, the project team related ecosystem services to management themes such as ecosystem-based forestry management, water resources management, species at risk management, etc. As demonstrated here, ecosystem-service models in addition to InVEST were completely compatible with this framework.

5.2 BASELINE CHARACTERIZATION AND PREPARATION

The primary way InVEST can support decision-making is through the comparison of service provision on the landscape between current and alternative future management scenarios. The models allow for comparison of service provision and value due to land-cover change that results from either climate or management interventions. Depending on the management priorities at each partner installation, either the present land cover map or a hypothetical future land cover map were used based on business-as-usual (BAU) management as the baseline condition.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY AND METHODOLOGY COMPONENTS

A brief overview of the InVEST component models with key assumptions and inputs that guide their application on installation sites are presented in the sections below. Further details are available in the InVEST online user manual (Sharp et al., 2014).

5.3.1 InVEST Carbon Storage & Sequestration Model

The InVEST Carbon Storage and Sequestration model estimates the current amount of carbon stored in a landscape and values the amount of sequestered carbon over time. First, it aggregates the biophysical amount of carbon stored in four carbon pools (aboveground living biomass, belowground living biomass, soil, and dead organic matter) based on LULC maps provided by users. A fifth optional pool represents carbon stored in harvested wood products, such as firewood, charcoal, or long-lived timber products. If the user provides a future LULC map, the carbon sequestration component of the model estimates expected change in carbon stocks over time. This portion of the model values the amount of carbon sequestered as an environmental service using additional data on the market value or social cost of carbon, its annual rate of change, and a discount rate. With optional inputs on probability distributions of carbon amount in different pools, the model can perform uncertainty analysis providing standard deviations for carbon estimates and a map showing where sequestration or emissions will occur with confidence.

5.3.2 InVEST Managed Timber Production

The InVEST Managed Timber Production Model estimates the net present value of legal timber harvests over user-defined time intervals. Based on timber harvest rate, market prices, extraction and management costs, and a discount rate, the model calculates the economic value of timber in user-defined management zones. This information serves timber companies, governments, and communities in exploring the benefit of timber production and its tradeoff with other forest ecosystem services.

5.3.3 InVEST Habitat Risk Assessment Model

The InVEST HRA model combines information about the degree to which the habitat of a given species is exposed to a stressor with information about consequences of exposure for the species. Exposure is a function of the degree of spatial and temporal overlap between habitat and a stressor, stressor intensity, and effectiveness of management strategies mitigating stressor impacts. The consequence of exposure is a function of the extent of change in area and structure due to the stressor, the frequency of disturbance relative to the historical disturbance regime, and attributes of the species either composing or residing in the habitat that influence the likelihood of its recovery from effects of the stressor. Exposure and consequence values are then combined to produce a risk value for each stressor-habitat combination. The model screens habitat risks under current and future scenarios of land use and its output can provide guidance for natural resource managers to tailor land uses to avoid impairment to quality and function of critical habitat. The HRA model enables the visualization of areas on the landscape where impacts due to training and testing activities, development projects, or other anthropogenic uses of installation lands may create tradeoffs between these activities and the provision of habitat for species at risk.

5.3.4 Training Capacity Model

The training capacity model is a new tool developed through this demonstration, and is designed to quantify the extent of military training and testing supported by natural habitats on DoD installations. It calculates the percentage of suitable natural landscape for infantry and vehicle training in each of the sub-training areas based on: 1) suitability and connectivity of LULC; and

2) frequency of training use characterizing troop demand for a realistic training and testing environment, and seasonal or annual restrictions on off-road vehicle maneuvering for habitat protection.

5.3.5 InVEST Water Yield Model

Water yield is an essential input to other water-related models even though it is not always an ecosystem-service end point. The InVEST Tier 1 water yield model uses an index of dryness (i.e., ratio of potential evapotranspiration to precipitation) to partition annual precipitation to evapotranspiration and runoff. The dryness index is a dominant factor that controls watershed water balance at annual time scale, making the water yield model valid for quantifying impacts of land use on runoff at a watershed scale. Model inputs include soil depth, mean annual precipitation, plant available water content, average annual potential evapotranspiration, land cover map, crop evapotranspiration, root depth, and shape file of (sub) watersheds. Model outputs include maps and tables of total and mean gross water yield per sub-watershed, total and mean water consumption per sub-watershed, and total and mean net water yield per sub-watershed.

5.3.6 InVEST Sediment Retention Model

The InVEST tier 1 sediment retention model predicts soil erosion, sediment yield, and sediment retention based on the Revised Universal Soil Loss Equation (RUSLE) (Wischmeier and Smith, 1978) and retention capacity of land uses. The RUSLE predicts sheet wash erosion based on the energetic ability of rainfall to move soil and cause erosion, the erodibility of a given soil type, slope length, erosion protection provided by the presence of vegetation, and management practices. The model can also value the landscape in terms of water quality maintenance or avoided erosion control cost, and determines how land use changes may impact the cost of sediment removal.

5.3.7 Auxiliary Models Beyond InVEST

5.3.7.1 Soil and Water Assessment Tool

The project team selected the SWAT as a Tier 2 alternative to InVEST sediment model to determine the complex interactions of hydrologic processes and generate a more refined estimate of sources and sinks of eroded materials. SWAT is a semi-distributed catchment-scale model that integrates the various water-budgeting and runoff-producing components of the terrestrial hydrological system including hydrology, erosion, soil temperature, plant growth, nutrients, pesticides, land management, channel and reservoir routing (Neitsch et al., 2011).

5.3.7.2 GLOBIO3

GLOBIO3 is a spatially explicit model that approximates biodiversity contained in different habitats and resulting from a change in the structure of ecosystems. The GLOBIO3 model (Alkemade et al., 2009) predicts mean species abundance (MSA) in response to land-use, fragmentation, infrastructure, climate change, and pollution threats, through a meta-analysis of the impact of each of these threats on individual species abundances.

5.3.7.3 HexSim

HexSim is a spatially-explicit individual-based modeling framework that simulates dynamics of one or more populations over time, given life cycle structure, event data, spatial data layers (e.g., landscape structure, habitat quality, stressor distribution), and basic simulation criteria, such as the length of each simulation (Lawler et al., 2011). HexSim is used as a Tier-2 alternative to the InVEST habitat risk assessment model to assess RCW nesting for Fort Benning.

5.4 FIELD TESTING

Successful application of InVEST and the ecosystem services approach at DoD installations requires the following five general operational phases. Depending on the complexity of the analyses and integrated training and ecosystem objectives, these steps are often best conducted in an iterative fashion, whereby management scenarios or model inputs are refined in response to results from early model runs (McKenzie et al., 2014; Rosenthal et al., 2014).

- Identify goals/objectives, focal ecosystem services, and drivers of future scenarios with relevant personnel and non-governmental organizations (NGO) partners.
- Learn InVEST and auxiliary models relevant to the ecosystem services of interest at the installation.
- Compile data and create scenario maps based on the InVEST user guide and scenario guidelines.
- Run InVEST and other models with calibration and validation, if data are available.
- Synthesize model outcomes and incorporate in decisions.

5.5 SAMPLING PROTOCOL

The project team collected the majority of GIS data (e.g., LULCs and soil maps) and background documents through contacts at three demonstration sites. The other data was retrieved from previous ESTCP/ SERDP projects, partnered NGOs and environmental consultants, and public data sources. For the Carbon Sequestration model, the aboveground carbon biomass data was collected from the National Biomass and Carbon Dataset (NBCD), a radar-derived, 30m-resolution, year-2000 baseline carbon estimate for the contiguous United States (Kellndorfer et al., 2000) and field estimates from sampling plots at JBLM and Fort Benning from project RC-2118 (M. Hurteau, Penn State University, Unpublished Data) for model validation. To validate the use of the HRA model, data available on the current distribution of species was collected from JBLM and Fort Benning and statistical analyses was used to test if current species distributions varied significantly with risk predicted to ecosystems or habitat. For hydrological models, the data was used on streamflow and suspended sediment concentration (SSC) archived previously by other SERDP/ESTCP projects and the U.S. Geological Survey (USGS) gauge at McBride Bridge (USGS # 02341800) for calibration and validation. A rating curve was used to generate a series of daily SSC as a function of flow rates.

5.6 SAMPLING RESULTS

For calibration of hydrology models, daily SSC curves were generated for 1996-2006, using the rating curve developed by USGS and verified by other researchers (Sharif and Balbach, 2008; Donigian, 2013). Generally, the interquartile range of SSC varies from 33.2 to 201.8 tons/day for wet seasons, and from 5.1 to 15.0 tons/day for dry seasons. For aboveground carbon biomass, the mean estimate from 110 plots at JBLM is ~186 Mg/ha; and the mean from 216 longleaf pine plots at Fort Benning is ~28 Mg/ha. Data for RCW cluster absences were generated following methods used by Lawler et al. (2011) using the centroids of 2013 cluster data.

6.0 PERFORMANCE ASSESSMENT

In the sections below, brief descriptions of data analysis for all POs are provided. Assessments for each of the three demonstration sites are presented separately to allow for variation in the objective definitions and application scales.

6.1 JOINT BASE LEWIS-MCCHORD

This section presents the assessment results for the demonstration at JBLM.

6.1.1 Summary of Scenarios (PO 7)

Through discussion with JBLM staff, the project team jointly identified two important policy drivers—training intensity and the budget for natural resource management— that influence future management practices and land uses. "Training intensity" represents the number of troops and frequency of training activities; generally, as these increase, so does disturbance to habitats. Training activities are also likely associated with expansion of laminated root rot (*Phellinus sulpharescens*), a root disease causing severe mortality in Douglas-fir forests (Hansen and Goheen, 2000), as motor vehicles transport infected woody debris with root rot spores (Foster, 2009), or possibly as training activities provide additional stress on infected trees (A. Kroll, personal communication, February 20, 2014). Root-rot-infested Douglas-fir forests that experience tree death and reduced canopy cover are susceptible to invasion by Scotch broom (Peterson and Prasad, 1998), but can also become native shrubland or pre-commercial forest (Foster, 2009). The "budget" for natural resource management correlates directly with the extent of invasive species control, tree planting, and grassland habitat maintenance on- and off-base. If sufficient budget is allocated to protecting species at risk and their habitats, JBLM personnel expect potentially less stringent training restrictions will be imposed post-ESA listing by the U.S. Fish and Wildlife Service on grasslands designated as either occupied or potential habitat. Projecting 20 years from a 2010 baseline, these drivers define the BAU scenario and four alternatives: High Budget-Decreased Training (HBDT), High Budget-Increased Training (HBIT), Low Budget-Decreased Training (LBDT), and Low Budget-Increased Training (LBIT). These scenarios vary in the total area of root rot infestation, Scotch broom expansion, tree planting, and training restrictions, as driven by training intensity and budget.

6.1.2 Quantification, Valuation, and Mapping of Ecosystem Services and their Tradeoffs (PO 1-6 & 8-9)

The five services that were identified as priorities for JBLM were modeled using InVEST. These services include: sustainability of Puget Sound Prairie, carbon sequestration, timber production, infantry training capacity, and vehicle training capacity. Training capacity and sustainability of the Puget Sound Prairie Ecosystem reflect the DoD's direct focus on maintaining military mission while complying with environmental regulations. Because Puget Sound Prairie includes multiple species of conservation concern, the "ecosystem provision of habitat" was used as a proxy for biodiversity (i.e., persistence of candidate, proposed, or listed species) and refer to sustainability of Puget Sound Prairie as an ecosystem service (Keith et al., 2013). Timber production from Douglas-fir forest provides income for natural resource management at JBLM. Finally, prospects of regulation for carbon sequestration on public lands drive DoD to consider how their management affects carbon dynamics. These services are interconnected via their dependence on LULC, providing an opportunity to observe tradeoffs and synergies that can inform management decisions.

The aggregate ecosystem service analysis illustrates potential consequences of training and budgetary variations (Table 2 and Figure 3) and can aid installation commanders in evaluating training and budget priorities, as well as justifying requests for modification. Information describing varied sets of ecosystem services may lead to different decisions. Based on the analysis and assumptions, if only those ecosystem benefits directly supporting the military mission and compliance with environmental regulation are considered, budget increases for resource management have a stronger influence than training intensity on maintaining current levels of ecosystem services. However, if indirect links to mission are considered (e.g., potential regulation of greenhouse gas emissions, emerging carbon markets, and revenues from timber production), both training activities and budget for resource management can be jointly leveraged to maintain current levels of ecosystem benefits (Figure 3).

Table 2. Ecosystem service provision for each scenario (absolute provision and percentage changes relative to BAU) at JBLM, WA.

Ecosystem Service	Infantry Training Capacity	Vehicle Training Capacity	Puget Sound Prairie Sustainability	Timber Production	Carbon Sequestration
Measure / **Management Scenarios**	Suitable area (1000 ha)	Suitable area (1000 ha)	Low-risk habitat (1000 ha)	Net present value (1M $)	Biomass (1000 Mg)
High Budget-Decreased Training	16.9 (7%)	4.86 (5%)	5.77 (28%)	74.9 (0%)	375 (57%)
High Budget-Increased Training	16.0 (1%)	4.90 (6%)	4.45 (-1%)	63.6 (-15%)	130 (-46%)
Business-As-Usual	15.9 (0%)	4.62 (0%)	4.51 (0%)	74.9 (0%)	239 (0%)
Low Budget-Decreased Training	16.0 (1%)	3.55 (-23%)	4.52 (0%)	74.9 (0%)	343 (44%)
Low Budget-Increased Training	15.1 (-5%)	3.60 (-22%)	3.98 (-12%)	62.1 (-17%)	92 (-62%)

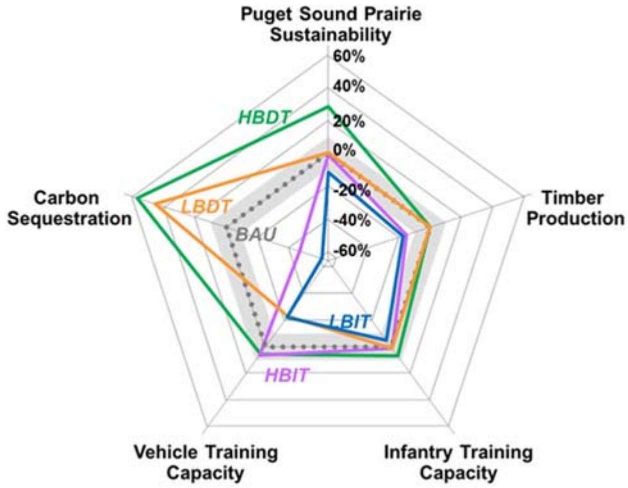

Figure 3. Percentage change of ecosystem service provision in four alternative scenarios relative to the BAU scenario.

BAU scenario: Puget Sound Prairie sustainability (low-risk area in ha), vehicle training capacity (applicable habitat area in ha), infantry training capacity (suitable landscape area in ha), carbon sequestration (Mg), and timber production (net present value in dollars for 2010-2030) at JBLM, WA. Alternative scenarios include LBIT, HBIT, HBDT, and LBDT.
Grey shade indicates 10% variation from BAU.

In addition, spatially explicit representations of ecosystem services could support details of resource management on the ground. At JBLM, the analysis identifies priority areas for sustaining current levels of ecosystem services and areas that might be targeted to improve service provision by shifting management funds to those areas and/or shifting some training activities to other areas where impacts on other benefits are minimized (Figure 4). For example, three centrally located training/impact areas with a mixed cover of forest/grassland are likely to maintain supply of multiple services if they are monitored and managed over time (Figure 4B). The large grassland area in the east region is a reasonable target for improvement, as it can provide a higher proportional increase in both area sustaining Puget Sound Prairie and training capacity with increased resource management budget and decreased training intensity (Figure 4C). This scenario-based approach can potentially support development of reasonable alternatives for proposed actions under NEPA, in negotiating shared objectives with community partners for buffer zone management, and in facilitating communication among different base divisions when discussing conflicting land uses.

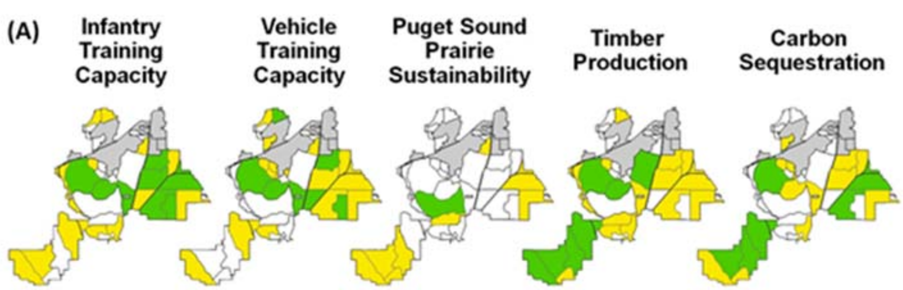

Figure 4A. Relative contribution of training areas (TA) and impact areas to total ecosystem service provision under the BAU scenario at JBLM, WA.

Green areas support >50% of total ecosystem service provision, yellow areas support 40%, and white areas contribute to the remaining 10%.

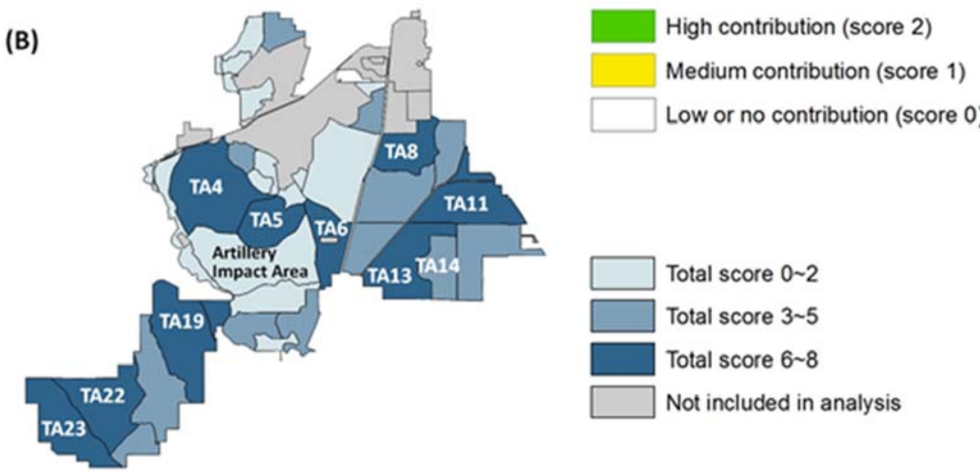

Figure 4B. Relative contribution of training and impact areas to all five ecosystem services based on the sum of scores.

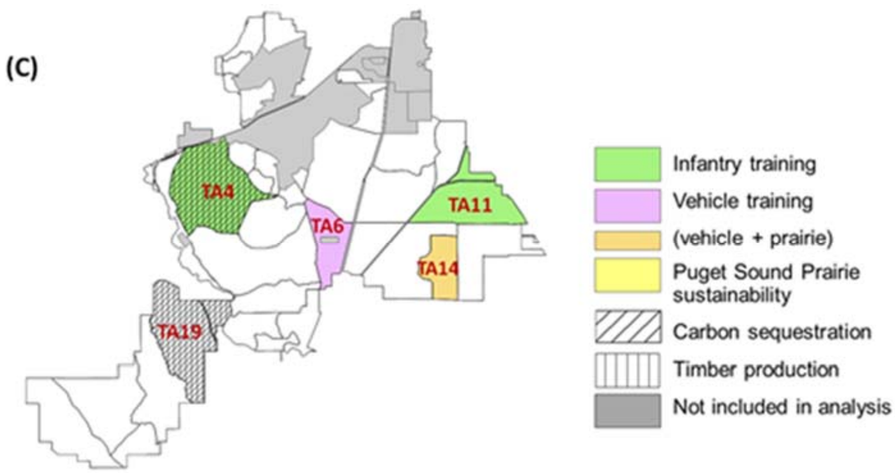

Figure 4C. Training/impact areas with the largest potential ecosystem service improvements from LBIT scenario to HBDT scenario.

Selected areas contribute to at least 25% of the improvement for each service. No training area falls in the "Puget Sound Prairie sustainability" category in this scenario comparison.

There are clear tradeoffs between training intensity and forest-related services, and a strong correlation between a reduced budget and decreased vehicle training capacity. Thus, management plans can be developed proactively to safeguard priority services when facing budget changes or shifts in military training goals. The results also indicate weak tradeoffs between policy drivers and provision of Puget Sound Prairie sustainability. Impacts imposed by one policy driver (e.g., increased training intensity) can be mostly offset with complementary change in the other driver (e.g., higher budget). The spatial distribution of low-risk areas sustaining Puget Sound Prairie indicates a synergy between artillery training and this rare ecosystem. Similar synergies between training activities and fire-dependent ecosystems have been described on other military installations (Warren et al., 2007; Stein et al., 2008). Together, spatial overlap of ecosystem services in their provision and improvement potential suggest multiple services can be secured or improved with efficiency.

6.2 FORT PICKETT

This section presents the assessment results for the demonstration at Fort Pickett.

6.2.1 Summary of Scenarios (PO 7)

ESTCP expressed interest in applying NatCap's ecosystem service approach and InVEST tools at multiple scales to demonstrate the flexibility of the InVEST models and approach. Thus, the demonstration at Fort Pickett was designed to highlight a simpler application, and focused on the management question of how to site new training facilities within the installation. In consultation with DoD personnel, the project team identified siting a potential new firing range as a focal question, and used the 35-acre FCC 17809 Qualification Training Range as a prototype in the analysis (Headquarters, Department of Army, 2010). Following consultation with Fort Pickett personnel, nine potential locations were identified within the impact area and each was treated as a separate siting scenario. The LULC (with the exception of water or wetland areas) were converted within the training range footprint to grassland to mimic the land conditions of the training range for each scenario.

6.2.2 Quantification, Valuation, and Mapping of Ecosystem Services and their Tradeoffs (PO 1-6 & 8-9)

The project team modeled three services identified as priorities for Fort Pickett: carbon sequestration, biodiversity, and sediment retention. Potential regulation of carbon sequestration on public lands drives DoD to consider how their management affects carbon dynamics. Conservation of biodiversity is also an important component of the DoD's ecological forestry initiative, which emphasizes managing forests for services in addition to timber production. Fort Pickett has a number of species at risk that require additional attention in impact assessments for new projects. Sedimentation resulting from training activities is the primary water quality problem at Fort Pickett. The installation is challenged to effectively control soil disturbance from maneuver training and reduce sediment entering the Nottoway River watershed, which supports diverse and unique biological and cultural resources. Carbon sequestration, biodiversity, and sediment retention are interconnected via their dependence on LULC, providing an opportunity to observe tradeoffs and synergies among services that can inform management decisions.

An evaluation of the ecosystem impacts was conducted on biodiversity, carbon storage, and sediment export under the baseline and nine alternative scenarios. The project team applied the GLOBIO3 model for analysis of biodiversity instead of InVEST because of limited information on species, which also demonstrates the flexibility of the ecosystem service approach for accommodating models outside of the InVEST package. The losses of ecosystem benefits were calculated from creating the new training range as the difference between each alternative scenario and the baseline (Table 2). For each of the three ecosystem impacts, nine potential locations were divided into three categories representing high, medium, and low loss as shown in Figure 5. Darker color indicates higher loss in ecosystem services and thus a less desirable siting choice. Carbon storage and biodiversity losses are mostly affected by the baseline LULC existing within alternative siting locations. Converting areas covered largely by forestland to open grasslands for training would result in higher loss in carbon biomass and species habitat (e.g., locations #1, #2, #4, and #9). Alternative locations contributing more to sediment export are often close to rivers or streams because of insufficient vegetation buffer to capture the soil erosion (e.g., locations #1, #2, #5, and #9). Some areas with large on-site soil erosion potential can result in relatively small sediment impacts if they are far from river networks (e.g., locations #7 and #8).

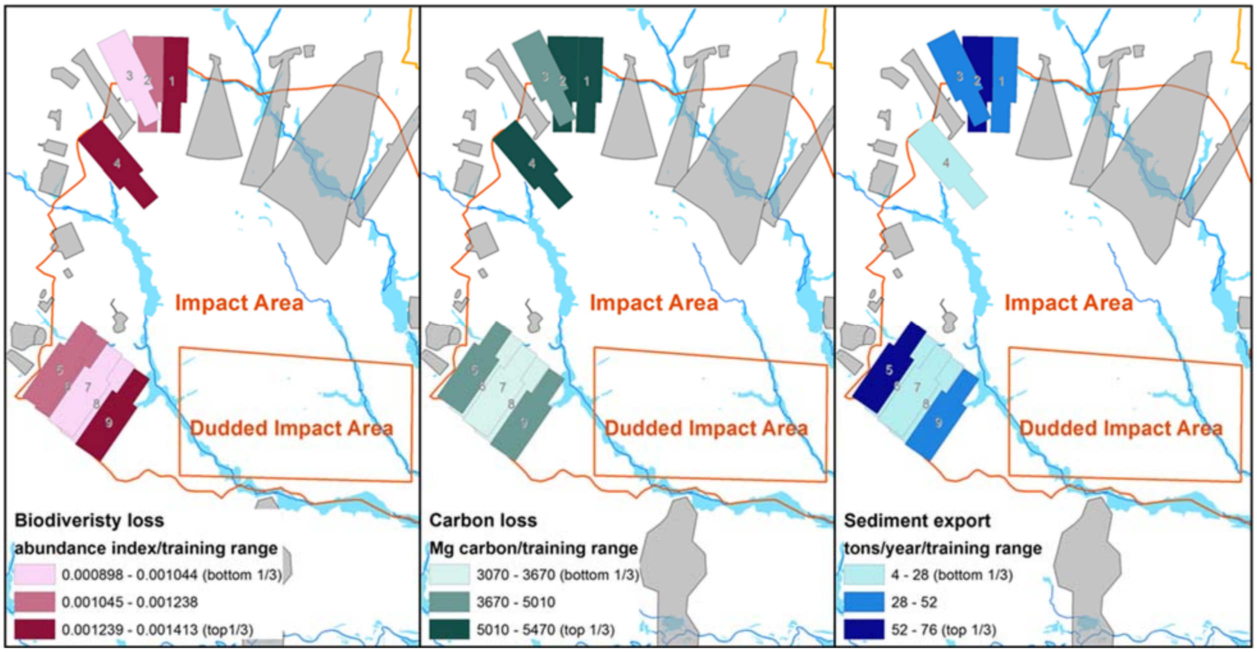

Figure 5. Ecosystem service losses on biodiversity, carbon storage, and sediment export under alternative scenarios for Fort Pickett, VA.

To inform site selection decisions, the results of ecosystem service impacts can be aggregated in a way that makes most sense to decision-makers. For example, if sediment erosion is the major concern for resource management due to regulation compliance, the best location(s) can be determined by following the sediment export results or by assigning a higher weight on sediment than others. Based on discussion with Fort Pickett personnel, equal weights were assigned to all three services to derive the aggregate results for the demonstration as an example. The potential locations were ranked based on the sum of normalized scores in biodiversity, carbon storage, and sediment export, where higher scores represent higher losses. Figure 6 clearly shows the ecological suitability of alternative locations based on three equal intervals of the aggregate scores. Sites in red (#1, #2, #4, and #9) indicate high ecosystem service loss or low ecological suitability for siting the new training range. Among these four locations, #2 and #9 show high losses in all three services, while #1 and #4 exhibit high losses in two out of three services. Locations most suitable for siting appear to cluster in the southwest region of the impact area (#6, #7, and #8 in green), where the baseline landscape has relatively large patches of grasslands and minimal interaction with the water network.

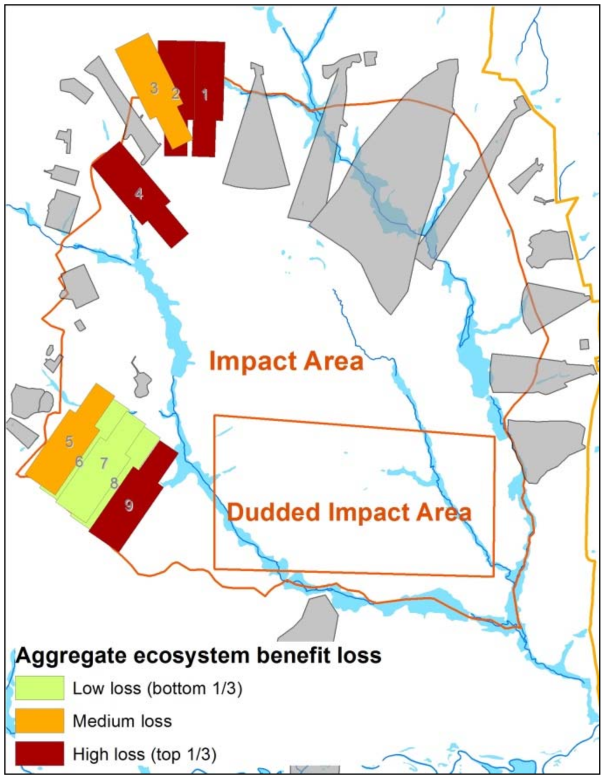

Figure 6. Aggregate ecosystem impacts on biodiversity, carbon storage, and sediment export under alternative scenarios for Fort Pickett, VA.

6.3 FORT BENNING

This section presents the assessment results for the demonstration at Fort Pickett.

6.3.1 Summary of Scenarios (PO 7)

Through iterative communications with Fort Benning personnel, three alternative land use scenarios were developed, as driven by management factors such as RCW protection, conversion of loblolly pine forests to long-leaf pine, soil erosion control, and troop realignment. The natural resource management and training activities are largely based around recovery for the federally endangered RCW that occurs at the installation. The priority for forestry management is to create and manage mature pine habitat for RCW nesting and foraging. The installation has also acquired some adjacent lands via the Army Compatible Use Buffer (ACUB) program to recover the RCW by restoring its habitat and reintroducing the species. RCW habitat is also threatened by a complex of tree diseases and pine beetles that cause declines or mortality in loblolly pine, a dominant tree across the base. When loblolly pines die, forestry staff replant areas with longleaf pine, which is important to RCW and is a longer-lived, native tree species that historically dominated the area. In addition, resource management at Fort Benning also focuses on soil erosion control from mechanized training activities and its mitigation using several types of BMPs.

Three alternative scenarios were developed from the 2013 baseline to evaluate ecosystem impacts resulting from training realignment and long-term ecology forestry management. The short-term diffuse training (SDT) scenario represents 20-year projection of the 2013 land use, resource management, and training activities as planned under BRAC/MCoE initiatives. Mechanized training is distributed on tank trails and open areas in three maneuver areas. It also encompasses longleaf pine restoration and development in ACUB. The short-term concentrated training (SCT) scenario represents 20-year BAU projection of land use and management from baseline. It differs from SDT by incorporating a new initiative to concentrate most mechanized training activities in the Good Hope Maneuver Training Area (GHMTA), which necessitate clear-cutting ~700-acre forest to create additional off-road corridors and new BMPs to mitigate soil disturbance. Comparing SCT with SDT reveals ecosystem impacts from concentrated mechanized training. The long-term ecological forestry (LEF) scenario represents 100-year BAU projection of land use and management from baseline. It captures transitions in forest composition and structure because of longleaf pine restoration as well as ACUB land acquisition for protecting RCW. Comparing this scenario with the SCT scenario reveals long-term versus short-term ecosystem benefits of ecological forestry management.

6.3.2 Quantification, Valuation, and Mapping of Ecosystem Services and Tradeoffs (PO 1-6 & 8-9)

Three services of interest were modeled for Fort Benning: risk to nesting habitat for RCW, sediment erosion and retention, and carbon sequestration. Maintaining habitat suitable for military training while complying with environmental regulation to recover federally endangered RCW is a priority at Fort Benning. Monitoring and mitigating sediment export caused by soil-disturbing activities are important targets for water resource management. The potential for future regulation of carbon sequestration on public lands motivates the DoD to consider how management on installations affects carbon dynamics. Risk to RCW nesting habitat, sediment retention, and carbon sequestration are interconnected via their dependence on LULC, particularly longleaf forest habitat, and examining potential responses of these services to changes in LULC provides an opportunity to observe tradeoffs and synergies that can inform management decisions at Fort Benning.

An ecosystem services approach was used to address two primary management questions at Fort Benning:

1. To what extent does the distribution of mechanized training across Fort Benning impact carbon sequestration, risk to RCW habitat, and sediment retention? Furthermore, what is the spatial distribution of these impacts across Fort Benning?
2. What are the short-term (20-year) versus long-term (100-year) benefits of ecological forestry management to carbon sequestration and risk to RCW habitat? Furthermore, what is the spatial distribution of these benefits across Fort Benning and adjacent ACUB lands?

The first question was addressed by quantifying, mapping, and comparing carbon sequestration, risk to RCW habitat, and sediment export between two 20-year scenarios (i.e., SDT and SCT) that differed only in the distribution of mechanized training and resulting clear-cut of forest for open maneuver in GHMTA. The more diffuse distribution of mechanized training had relatively small, but positive effects on all ecosystem services/impacts modeled (Figure 7). Concentrating mechanized training led to a decrease of 13,000 metric tons (9%) of sequestered carbon from the 2013 baseline, because of forest clear-cut for training purposes (most orange areas in figure). Notably, active longleaf pine restoration carried out by clear-cutting loblolly pine plantations yields a sharp loss of carbon across the installation in these two scenarios (red in figure). Concentrated training also decreases by 80 acres (ac) the low-risk RCW habitat (0.3%) over the SDT scenario. However, both 20-year scenarios show a 30% increase in low-risk habitat from the 2013 baseline, most of which occurs in the lands, where recently burned and replanted longleaf pine forest ages and grows to larger sizes favored by RCW for nesting. Concentrated training yields higher soil erosion and an increase of 1,600 tons/year in sediment exported into the water networks (10% in GHMTA, 1% in watershed), even considering enhanced BMPs for erosion control. The excess soil erosion from off-road mechanized training activities compounded with highly erodible soils in the GHMTA result in much higher soil erosion rates.

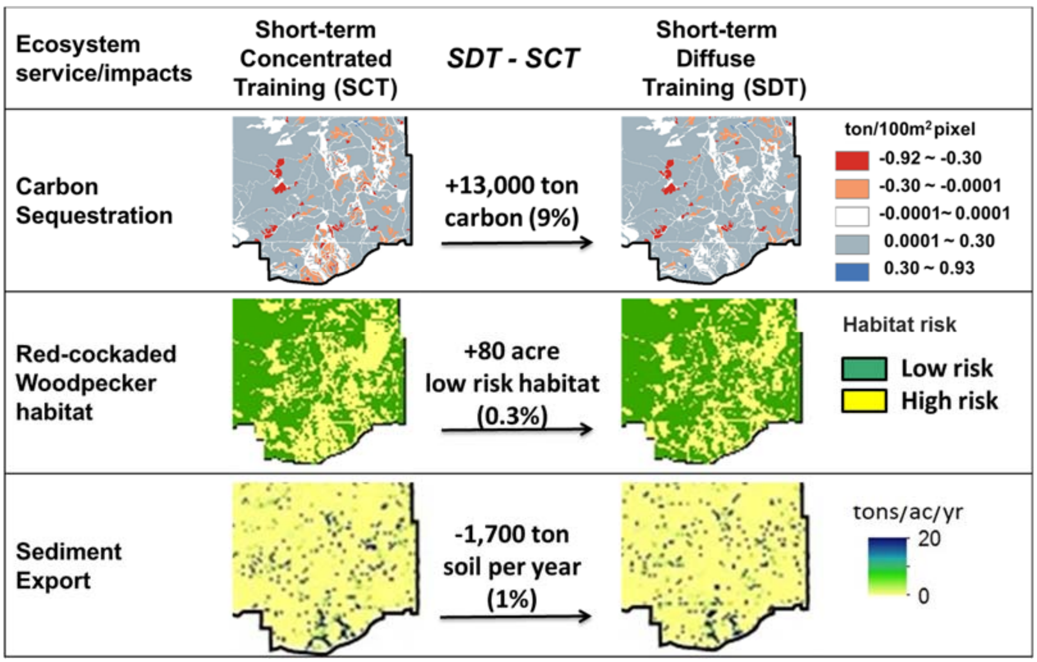

Figure 7. Ecosystem impacts on carbon sequestration, risk to RCW habitat, and sediment export between SDT and SCT scenarios for Fort Benning, GA.

Maps are zoomed-in views of ecosystem impacts in the GHMTA, where most land-use changes occur in these scenarios. Differences in ecosystem impacts reported are estimated for the entire installation/watershed between the two scenarios.

The second question was addressed by quantifying, mapping, and comparing carbon sequestration and risk to RCW habitat[1] under two alternative management scenarios that both included a concentrated distribution of mechanized training, but differed in forestry management through time. The LEF scenario employs larger scale gradual conversion of dead loblolly and mixed pine stands to longleaf pine forest over the SCT, which captures more active restoration of longleaf

[1] The sediment model for the LEF scenario was not assessed because of the substantial uncertainty associated with hydrological parameters for prediction of 100 years. Without considering long-term variations in climate and training activities, the sediment assessment for the SCT scenario remains valid for the LEF scenario as the transition among different forest types has minor influence on hydrological models.

pine by clear-cutting loblolly plantations ~5 years from the baseline. The LEF scenario shows a large, positive impact on carbon sequestration and greater availability of low-risk RCW habitat. While carbon is lost during conversion activities, it is gained with the aging of forest stands, resulting in a net increase of 532,000 tons of carbon (360%) in the LEF scenario relative to the SCT scenario. Similarly, low-risk RCW habitat increased with the aging of forest stands in the LEF scenario so that high-risk areas remained only where open habitat with little cover extended in patches greater than 150m, potentially acting as movement barriers for RCW. An additional 8,200 acres of low-risk RCW habitat (31%) is gained during the LEF scenario relative to the SCT scenario.

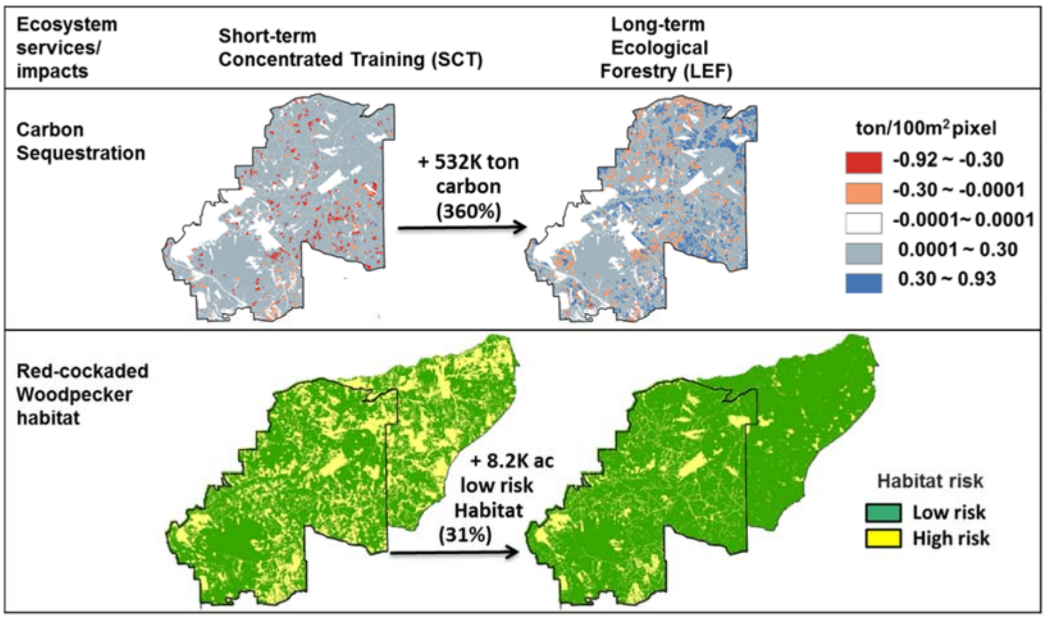

Figure 8. Ecosystem impacts on carbon sequestration and risk to RCW habitat between SCT and LEF scenarios for Fort Benning and ACUB areas, GA.
Carbon sequestration for ACUB parcels is not shown for confidentiality

6.4 QUALITATIVE ANALYSIS (PO 10-13)

The qualitative analysis suggests several opportunities for the ecosystem services approach and InVEST tools to inform and improve land and water management decisions regularly made on DoD installations. First, the approach is useful in comprehensive spatial planning and land management decisions where InVEST models can provide spatially explicit information on ecosystem services that is amenable to the existing Ecosystem Based Management framework for DoD. Second, the approach uses potential future scenarios developed jointly with stakeholders to map and value synergies and tradeoffs in ecosystem services. Such scenario-driven analyses can help visualize potential consequences of actions or policies and reduce costs of unanticipated or unintended conflicts. Third, the approach provides spatially explicit, quantitative measures of ecosystem services and impacts to complement field observations and qualitative measures that are more common in current environmental impact assessment. Notably, InVEST makes it easier to incorporate additional services that are not often considered in impact assessments (e.g., carbon sequestration) into the decision process. Forth, an ecosystem services approach can support ecological forestry management by helping evaluate and optimize multiple values of their forests for training, wildlife habitat provision, and carbon sinks. Fifth, InVEST models can serve as a cost-saving alternative to complex modeling tools to assess the relative magnitude of ecosystem impacts. Installations can use the information to prioritize monitoring site selection in order to comply with environmental regulations.

Due to lack of technical capacity and additional software certification requirements, installation staff at three demonstration sites were unable to use InVEST independently, but they provided positive feedback on the value of the analytical approach and the scenario generation process. They are interested in adopting this approach if current barriers are resolved.

For the Fort Benning demonstration, the project team evaluated POs related to scenario development, uncertainty analysis, model validation, decision supporting opportunities, and ease of use with a post-demonstration survey of installation personnel. The response score ranged from 3.9 to 4.6 on a 5-point Likert scale, indicating respondents generally agreed with statements assessing demonstration success in meeting each objective. The average score across all survey questions was 4.1, indicating overall agreement with survey statements and acceptance of project outcomes.

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7.0 COST ASSESSMENT

This section estimates the costs of a full implementation at a given installation.

7.1 COST MODEL

The primary cost of quantifying and valuing ecosystem services to inform installation management is the specialized labor involved in applying the models and interpreting results.

Hydrology data are often available at no cost from the USGS, the U.S. Department of Agriculture (USDA), the Environmental Protection Agency (EPA), and many other research institutions in the United States. InVEST also provides global/regional average data for some water model inputs as a starting point when local data are not available. However, sometimes users may prefer local data, which require additional resources to purchase data sets or to monitor on site. The cost of obtaining hydrology data is thus a very wide range: $0 to $300,000+ in the rare occasions where original data are desired. Non-hydrology data, such as real estate prices, if desired, are estimated to cost $150.

Standard personal computers are required; and although most staff already have personal computers, the cost to acquire new computers is $1,000 each for a desktop model. Either free, open source GIS software such as QGIS, or commercially available ESRI-ArcGIS software (for which DoD has a site license), is required by each team member for managing the project, running models and analyzing the results.

Scaling of the application of InVEST across the DoD will require security certification of InVEST software. This would be a one-time cost to the department, but would not affect individual sites once the software was certified for use.

7.2 COST DRIVERS

The primary, direct cost of quantifying and valuing ecosystem services is scientific or technical labor, with most labor at a GS-9 salary level. Labor costs for professional, scientific, and technical labor have risen approximately 2%/year[2] over the past 5 years. Data availability is a key potential cost. Costs are falling with the availability increasing of good, low cost, or free data; and costs are dropping for primary data collection. If primary hydrological data are required, newer technologies are allowing lower cost collection techniques. The cost of computing power and software costs also are falling. Further, installation management will continue to experience growing indirect costs for managing installation lands as performance demands and regulatory constraints increase. Additional considerations will arise as neighboring communities intensify their land-use and put further pressures and constraints on installations. The NatCap approach and InVEST tools, allowing management to quantify multiple ecosystem service trade-offs and present clear, spatially explicit management options, will productively focus the decision process, and reduce the uncertainty and indirect costs that come from working with multiple stakeholders and constraints.

[2] Bureau of Land Management Employment Cost Index Series Id:CIU2015400000000A

Table 3. Cost elements and estimates.

Cost Element	Data Tracked During Demonstration	Estimated Costs
Hydrology data collection	a) Material costs of hydrology measurement equipment; and b) Labor (contract for tech. time) for collecting hydrology data	$0-$300,000
Non-hydro data collection	a) Cost of purchasing local real estate data; b) Other purchased data collections (if needed & acquired)	$149
Computer & Software	Cost of five laptops and ArcGIS software	$10,000
Project Manager (GS-9)	Management time (person months) to determine relevant models, set up team, manage implementation, and scenario development	3 +/-1 person months $
GIS Analyst (GS-7 or -9)	Time (person months) applying InVEST to installation, including data collection, scenario development, model runs, and post model decision analysis. Includes several iterations of modeling.	7.5 +/-1.5 person months $
Subject Matter Experts (installation dependent) (GS-9)	Time (person months) working on applying InVEST to installation, including data collection, scenario development, model runs, and post model decision analysis. In this demonstration, an economist was included as part of the team at all three installations, as well as a hydrologist and ecologist at two installations. Additional expertise, such as in fisheries or coastal engineering, may be required at installations on the coast, depending on the objectives.	21.2 +/-1.5 person months $
Installation Management	No data tracked	

7.3 COST ANALYSIS AND COMPARISON

A basic DoD site is assumed to have multiple environmental and operational constraints on land use, such as training mission, threatened species, and downstream water users. It may also have multiple stakeholder groups, including neighboring communities and multiple departments at the installation. For the purpose of cost analysis, it was assumed that the installation has: a decision context that would motivate installation management involvement and benefit from an ecosystem service valuation approach; multiple natural resource managers from different divisions who are willing to participate in scenario development; a site license for ESRI ArcGIS software; sufficient data to proceed with using InVEST models; and labor rates are similar to the locality pay area of Atlanta-Sandy Springs-Gainesville, GA-AL.

The time frame for quantifying and valuing ecosystem services to inform installation management takes 8+ months for an installation that has an upcoming decision and can get installation management input for scenario selection. The usual time periods are:

1. Learn InVEST: 2 weeks ($12,000);
2. Collect and pre-process data: 1-2 months ($24,000);
3. Develop Scenarios: 2 months ($48,000);
4. Model Runs (steps 2-4 will iterate and overlap): 2 months ($48,000); and
5. Post model decision analysis: 1-2 months ($48,000).

The actual time may take much longer if there are delays in getting input from installation management and other stakeholders. Subsequent iterations of the basic steps above can occur much more rapidly and thus are likely to be less costly. The life cycle for a decision process is normally less than 1 year. Experience with the process and reuse of earlier data would theoretically allow future decisions to be made more quickly and less expensively. Table 4 below shows the actual cost through the demonstration summarized by cost elements listed in Table 3.

Table 4. Demonstration: Experience at Three Installations.

Cost Item	Predicted Cost	Average Actual Cost	Fort Benning Cost	JBLM Cost	Fort Pickett Cost
Data Collection	$77,000	$100,049			
Computers & Software	$12,000	$4,000			
Project Manager – person months ($)	2.5	4.2 ($24,000)	3.9 ($22,000)	7.2	1.6
GIS Analyst – person months ($)	7.5	7.3 ($41,000)	4.4 ($25,000)	13.9	3.6
Subject Matter Experts - person months ($)	19.5	21.2 ($116,000)	35.3 ($98,000)	20.8	7.4
Total	**$255,000**	**$285,049**	**$545,000**	**$226,000**	**$70,000**

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8.0 IMPLEMENTATION ISSUES

This section presents the lessons learned through the demonstration, support for technology transfer, and technical requirements for adopting this methodology.

The project team learned five key lessons throughout the demonstration of an ecosystem service approach to multiple-use landscape management on DoD installations. First, an iterative and interactive approach was found to define when, and what kind of ecosystem service information was needed; this step was critical to create credible science that could be used in decision processes. The second conclusion was that it was important to take the time to clearly articulate the appropriate use of InVEST to support novel outcomes in DoD management. The InVEST tools are designed to require relatively few data to broaden the range of applicable locations and decision contexts. As for any simple models, simplifying assumptions are inherent, and thus InVEST is typically most useful for comparing tradeoffs and relative magnitudes of ecosystem services among multiple alternatives of land use planning and natural resource management scenarios. In contrast, InVEST was not as reliable for predicting precise estimates of the absolute magnitudes of ecosystem services at a particular place or time. The tradeoff between ease and relative speed of simple models and greater comprehensiveness of more detailed models will help dictate an appropriate modeling approach to match regulatory or policy needs. Third, the project team found ecosystem value metrics are most relevant when they are conveyed in measures related to the organization's decision context. Although monetary economic values of ecosystem services are commonly understandable and can be convenient in supporting decisions, non-monetary measures of ecosystem services (e.g., water quality threshold values, habitat area to support species) often play a more vital role in government decision-making. Fourth, the successful adaptation of InVEST required technical capacity within organizations. Although some technical support is available through NatCap and on-line user forums, often technical needs exceed these resources. For example, technical capacity/expertise is needed to parameterize, troubleshoot and run InVEST, make scientific judgments about how to fill knowledge gaps (e.g., installation-level input data), and understanding methods for analyzing and visualizing results. Lastly, it is suggested that more progressive policy incentives and centralized data support may facilitate adoption of ecosystem service approaches and tools by minimizing current barriers, such as limited technical capacity and staff time at the installations.

To facilitate technology transfer, the project team provides guidance for installation managers to review and continuously reference in the application of InVEST and the NatCap approach, including the InVEST User Guide (Sharp et al., 2014); guidance for scenario development (McKenzie et al., 2012); as well as peer-reviewed publications of InVEST applications (e.g., Goldstein et al., 2012; Rucklehaus et al., 2013; Bhagabati et al., 2014; Hamel and Guswa, 2014; McKenzie et al., 2014). Two new resources also were developed to further help adoption of the ecosystem service approach and InVEST tools across the DoD: 1) novel pre- and post-processing capabilities to standardize some labor-intensive work necessary for applying InVEST models typically used on DoD installations; and 2) an online training curriculum, which will serve as a primer on the ecosystem service approach and InVEST tools through the Stanford Online training platform. This course includes specific examples from DoD demonstrations to illustrate how the approach has worked in each case, and highlights key methods and tools available for future implementation. The course will be open to DoD personnel and other interested parties in 2015.

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APPENDIX A

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